PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re the Application of

Sbiaa RACHID et al.

Application No.: 10/668,998

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For: THIN-FILM MAGNETIC HEAD WITH CURRENT-PERPENDICULAR-TO-THE-PLANE

CLAIM FOR PRIORITY

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

The benefit of the filing date of the following prior foreign application filed in the following foreign country is hereby requested for the above-identified patent application and the priority provided in 35 U.S.C. §119 is hereby claimed:

Japanese Patent Application No. 2002-279569 Filed September 25, 2002

In support of this claim, a certified copy of said original foreign application:

☒ is filed herewith.

It is requested that the file of this application be marked to indicate that the requirements of 35 U.S.C. §119 have been fulfilled and that the Patent and Trademark Office kindly acknowledge receipt of this document.

Respectfully submitted,

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1 Title of Invention

Thin-Film Magnetic Head

2 Claims

[Claim 1] A thin-film magnetic head comprising:

an antiferromagnetic layer;

a pinned layer whose direction of magnetization is fixed by exchange-coupling with said antiferromagnetic layer;

a free layer whose direction of magnetization varies according to external magnetization;

an intermediate layer disposed between said pinned layer and said free layer; and

a pair of electrode layers for supplying a sense current in a layer thickness direction of said free layer;

one of said electrode layers being connected to said pinned layer.

[Claim 2] A thin-film magnetic head according to claim 1, wherein said pinned layer comprises a first ferromagnetic layer in contact with said antiferromagnetic layer, a second ferromagnetic layer whose direction of magnetization is opposite from that of said first ferromagnetic layer, and a nonmagnetic spacer layer disposed between said first and second ferromagnetic layers;

said one electrode layer connected to said pinned layer being in contact with a track-widthwise side face of said second ferromagnetic layer but not in contact with a track-widthwise side face of said first ferromagnetic layer.

[Claim 3] A thin-film magnetic head according to claim 2, wherein a face of said second ferromagnetic layer opposing said first ferromagnetic layer has an area smaller than that of a face of

said first ferromagnetic layer opposing said second ferromagnetic layer.

[Claim 4] A thin-film magnetic head according to one of claims 1 to 3, wherein said intermediate layer is formed from an electrically conductive material.

[Claim 5] A head gimbal assembly having a thin-film magnetic head mounted with a gimbal;

said thin-film magnetic head comprising:

an antiferromagnetic layer;

a pinned layer whose direction of magnetization is fixed by exchange-coupling with said antiferromagnetic layer;

a free layer whose direction of magnetization varies according to external magnetization;

an intermediate layer disposed between said pinned layer and said free layer; and

a pair of electrode layers for supplying a sense current in a layer thickness direction of said free layer;

one of said electrode layers being connected to said pinned layer.

[Claim 6] A hard disk apparatus comprising a hard disk adapted to write magnetic information therein, and a thin-film magnetic head for reading said magnetic information of said hard disk;

said thin-film magnetic head comprising:

an antiferromagnetic layer;

a pinned layer whose direction of magnetization is fixed by exchange-coupling with said antiferromagnetic layer;

a free layer whose direction of magnetization varies according to external magnetization;

an intermediate layer disposed between said pinned layer and said free layer; and

a pair of electrode layers for supplying a sense current in a layer thickness direction of said free layer;

one of said electrode layers being connected to said pinned layer.

[Claim 7] A method of making a thin-film magnetic head, said method comprising the steps of:

forming an antiferromagnetic layer;

forming a pinned layer whose direction of magnetization is fixed by exchange-coupling with said antiferromagnetic layer;

forming a free layer whose direction of magnetization varies according to external magnetization;

forming an intermediate layer disposed between said pinned layer and said free layer; and

forming a pair of electrode layers for supplying a sense current in a layer thickness direction of said free layer;

one of said electrode layers being formed so as to be connected to said pinned layer.

[Claim 8] A method of making a thin-film magnetic head according to claim 7, wherein said pinned layer comprises a first ferromagnetic layer in contact with said antiferromagnetic layer, a second ferromagnetic layer whose direction of magnetization is opposite from that of said first ferromagnetic layer, and a nonmagnetic spacer layer disposed between said first and second ferromagnetic layers;

said one electrode layer connected to said pinned layer being formed in contact with a track-widthwise side face of said second ferromagnetic layer but not in contact with a track-

widthwise side face of said first ferromagnetic layer.

[Claim 9] A method of making a thin-film magnetic head according to claim 7, wherein said pinned layer comprises a first ferromagnetic layer in contact with said antiferromagnetic layer, a second ferromagnetic layer whose direction of magnetization is opposite from that of said first ferromagnetic layer, and a nonmagnetic spacer layer disposed between said first and second ferromagnetic layers;

said method comprising the steps of:

forming a magnetic layer to become said second ferromagnetic layer so as to cover said first ferromagnetic layer having a desirable pattern after obtaining said first ferromagnetic layer; and

patterning said magnetic layer to become said second ferromagnetic layer by utilizing a mask so as to obtain said second ferromagnetic layer having a desirable form;

wherein a projected area of said mask onto said first ferromagnetic layer is smaller than the area of a face of said first ferromagnetic layer opposing said mask.

3 Detailed Description of Invention

[0001]

[Technical Field of the Invention]

The present invention relates to a thin-film magnetic head for reading magnetic information of a hard disk and the like by utilizing a magnetoresistance effect, a head gimbal assembly, a hard disk apparatus, and a method of making a thin-film magnetic head.

[0002]

[Prior Art]

MR (Magneto Resistive) heads have been in use as thin-film magnetic heads for reading magnetic information of hard disks. The MR heads utilize a magnetoresistance effect in which a magnetic material changes its ohmic value due to changes in external magnetic fields (e.g., leakage magnetic fields from hard disks) when a current is caused to flow through the magnetic material. This magnetoresistance effect can substantially be realized by an MR film in which a pinned layer whose direction of magnetization is fixed by exchange-coupling with an antiferromagnetic layer, a free layer whose direction of magnetization varies according to external magnetic fields, an intermediate layer disposed therebetween, and the like are stacked. In GMR (Giant Magneto Resistive) heads utilizing a giant magnetoresistance effect, the intermediate layer is formed from an electrically conductive material such as Cu.

[0003]

A predetermined sense current is supplied to the MR film of a magnetic head. Then, the angle between the respective directions of magnetization of the pinned layer and free layer changes due to external magnetic fields. The resistance to the sense current is the lowest when the respective directions of magnetization of the individual layers coincide with each other, and is the highest when the directions of magnetization are opposite from each other. Reading such a change in resistance as a voltage value can reproduce the magnetic information written in hard disks.

[0004]

Meanwhile, in thin-film magnetic heads, the CIP (Current In Plane) structure in which the sense current flows in a planar

direction of the MR film and the CPP (Current Perpendicular to Plane) structure in which the sense current flows in a direction (film thickness direction) perpendicular to the MR film have been developed (see, for example, the following patent document 1). Since a magnetic shield layer itself can be used as an electrode, the latter CPP structure is substantially free from short-circuiting (insulation failure) between the magnetic shield layer and MR film which may become problematic in the narrower lead gap to be achieved in the CIP structure. Therefore, the CPP structure is quite advantageous in attaining a higher recording density in hard disks. Examples of heads employing the CPP structure include TMR (Tunnel-type Magneto Resistive) heads utilizing a magnetoresistance effect occurring in a tunnel junction, and CPP-GMR heads.

[0005]

[Patent Document 1]

Japanese Patent Application No. 2000-105912 (Fig. 2)

[0006]

[Problem to be Solved by the Invention]

However, the conventional thin-film magnetic heads of CPP structure have the following problem. Conventionally, a pair of electrode layers for supplying the sense current to the MR film have normally been formed on the upper side of the MR film and the lower side of the antiferromagnetic layer, respectively. Namely, the sense current also flows through the antiferromagnetic layer that does not directly contribute to magnetoresistance changes. As a consequence, the antiferromagnetic layer generates so-called parasite resistance, thus failing to yield a high magnetoresistance change ratio.

[0007]

In order to overcome the above-mentioned problem, it is an object of the present invention to provide a thin-film magnetic head, a head gimbal assembly, a hard disk apparatus, and a method of making a thin-film magnetic head, which can realize a high magnetoresistance change ratio.

[0008]

[Means for Solving Problem]

(1) For achieving the above-mentioned object, the thin-film magnetic head of the present invention comprises an antiferromagnetic layer; a pinned layer whose direction of magnetization is fixed by exchange-coupling with the antiferromagnetic layer; a free layer whose direction of magnetization varies according to external magnetization; an intermediate layer disposed between the pinned layer and the free layer; and a pair of electrode layers for supplying a sense current in a layer thickness direction of the free layer; one of the electrode layers being connected to the pinned layer.

[0009]

In such a thin-film magnetic head, the sense current flows through the free layer, intermediate layer, and pinned layer, but basically does not flow through the antiferromagnetic layer. Therefore, the antiferromagnetic layer does not become resistance to the sense current, whereby a high magnetoresistance change ratio can be obtained.

[0010]

Preferably, in the thin-film magnetic head of the present invention, the pinned layer comprises a first ferromagnetic layer in contact with the antiferromagnetic layer, a second

ferromagnetic layer whose direction of magnetization is opposite from that of the first ferromagnetic layer, and a nonmagnetic spacer layer disposed between the first and second ferromagnetic layers; the one electrode layer connected to the pinned layer being in contact with a track-widthwise side face of the second ferromagnetic layer but not in contact with a track-widthwise side face of the first ferromagnetic layer.

[0011]

When the pinned layer is constituted by two layers whose directions of magnetization are opposite from each other, a magnetic field is closed between the first and second ferromagnetic layers, whereby the influence of the magnetic field of the pinned layer upon the free layer can greatly be reduced. The inventors have also found that, when forming the pinned layer into such a configuration, the maximum magnetoresistance change (difference between the magnetoresistance value at the time when the respective magnetizations of the free layer and pinned layer are in parallel and the magnetoresistance value at the time when they are not in parallel) can be made higher if the sense current is caused to flow through the second ferromagnetic layer alone without flowing through the first ferromagnetic layer, whereby the magnetoresistance change ratio can be improved. Namely, when a configuration in which the electrode layer connected to the pinned layer is in contact with a track-widthwise side face of the second ferromagnetic layer but not in contact with a track-widthwise side face of the first ferromagnetic layer is employed, the sense current basically flows through the second ferromagnetic layer but not through the first ferromagnetic layer, whereby a high magnetoresistance change ratio can be realized.

[0012]

Preferably, in the case where the pinned layer comprises the first and second ferromagnetic layers, a face of the second ferromagnetic layer opposing the first ferromagnetic layer has an area smaller than that of a face of the first ferromagnetic layer opposing the second ferromagnetic layer.

[0013]

For obtaining the second ferromagnetic layer having a desirable pattern, a mask corresponding to this pattern is utilized. When the above-mentioned area of the second ferromagnetic layer is smaller than the above-mentioned area of the first ferromagnetic layer, the whole surface of the face of the second ferromagnetic layer on the first ferromagnetic layer side can oppose the first ferromagnetic layer even if the mask forming position shifts to some extent. As a consequence, the magnetization of the second ferromagnetic layer can be fixed firmly, whereby so-called pin inversion can effectively be suppressed.

[0014]

In the thin-film magnetic head of the present invention, the intermediate layer may be formed from an electrically conductive material. In this case, the thin-film magnetic head becomes a so-called GMR head of CPP structure. Alternatively, the intermediate layer may be formed from an insulating material, so as to become a TMR head. Though the CPP-GMR is less likely to yield a magnetoresistance change ratio as high as that of TMR, a magnetoresistance change ratio higher than that conventionally available can be realized in the configuration of the present invention.

[0015]

The head gimbal assembly of the present invention is a head gimbal assembly having a thin-film magnetic head mounted with a gimbal; the thin-film magnetic head comprising an antiferromagnetic layer; a pinned layer whose direction of magnetization is fixed by exchange-coupling with the antiferromagnetic layer; a free layer whose direction of magnetization varies according to external magnetization; an intermediate layer disposed between the pinned layer and the free layer; and a pair of electrode layers for supplying a sense current in a layer thickness direction of the free layer; one of the electrode layers being connected to the pinned layer.

[0016]

The hard disk apparatus of the present invention is a hard disk apparatus comprising a hard disk adapted to write magnetic information therein, and a thin-film magnetic head for reading the magnetic information of the hard disk; the thin-film magnetic head comprising an antiferromagnetic layer; a pinned layer whose direction of magnetization is fixed by exchange-coupling with the antiferromagnetic layer; a free layer whose direction of magnetization varies according to external magnetization; an intermediate layer disposed between the pinned layer and the free layer; and a pair of electrode layers for supplying a sense current in a layer thickness direction of the free layer; one of the electrode layers being connected to the pinned layer.

[0017]

The head gimbal assembly and hard disk apparatus can realize a high reproducing output in the hard disk apparatus since they are equipped with the above-mentioned thin-film magnetic

head.

[0018]

(2) The method of making a thin-film magnetic head in accordance with the present invention comprises the steps of forming an antiferromagnetic layer; forming a pinned layer whose direction of magnetization is fixed by exchange-coupling with the antiferromagnetic layer; forming a free layer whose direction of magnetization varies according to external magnetization; forming an intermediate layer disposed between the pinned layer and the free layer; and forming a pair of electrode layers for supplying a sense current in a layer thickness direction of the free layer; one of the electrode layers being formed so as to be connected to the pinned layer.

[0019]

In thus obtained thin-film magnetic head, the sense current flows through the free layer, intermediate layer, and pinned layer, but basically does not flow through the antiferromagnetic layer. Therefore, the antiferromagnetic layer does not become resistance to the sense current, whereby a high magnetoresistance change ratio can be obtained.

[0020]

Preferably, in the method of making a thin-film magnetic head in accordance with the present invention, the pinned layer comprises a first ferromagnetic layer in contact with the antiferromagnetic layer, a second ferromagnetic layer whose direction of magnetization is opposite from that of the first ferromagnetic layer, and a nonmagnetic spacer layer disposed between the first and second ferromagnetic layers; the one electrode layer connected to the pinned layer being formed in

contact with a track-widthwise side face of the second ferromagnetic layer but not in contact with a track-widthwise side face of the first ferromagnetic layer.

[0021]

In thus obtained thin-film magnetic head, the sense current basically flows through the second ferromagnetic layer but not through the first ferromagnetic layer, whereby a high magnetoresistance change ratio can be realized.

[0022]

Preferably, in the method of making a thin-film magnetic head in accordance with the present invention, the pinned layer comprises a first ferromagnetic layer in contact with the antiferromagnetic layer, a second ferromagnetic layer whose direction of magnetization is opposite from that of the first ferromagnetic layer, and a nonmagnetic spacer layer disposed between the first and second ferromagnetic layers; the method comprising the steps of forming a magnetic layer to become the second ferromagnetic layer so as to cover the first ferromagnetic layer having a desirable pattern after obtaining the first ferromagnetic layer; and patterning the magnetic layer to become the second ferromagnetic layer by utilizing a mask so as to obtain the second ferromagnetic layer having a desirable form;

whereas a projected area of the mask onto the first ferromagnetic layer is smaller than the area of a face of the first ferromagnetic layer opposing the mask.

[0023]

When a mask having such a size is utilized, the whole surface of the face of the second ferromagnetic layer on the first ferromagnetic layer side can oppose the first ferromagnetic layer

even if the mask forming position shifts to some extent. As a consequence, the magnetization of the second ferromagnetic layer can be fixed firmly, whereby so-called pin inversion can effectively be suppressed.

[0024]

[Mode for Carrying Out the Invention]

In the following, preferred embodiments of the present invention will be explained in detail with reference to the accompanying drawings. Constituents identical to each other will be referred to with numerals identical to each other without repeating their overlapping descriptions.

[0025]

[First Embodiment]

Fig. 1 is a view schematically showing the thin-film magnetic head in accordance with an embodiment, illustrating the vicinity of a position slightly inside from its recording medium opposing face (hereinafter referred to as "air bearing surface (ABS)" side). The thin-film magnetic head 10 is a GMR head utilizing a giant magnetoresistance effect. It comprises a buffer layer 31; an antiferromagnetic layer (referred to as "AF" in the drawing) 32; a pinned layer 36 having a three-layer structure, whose direction of magnetization is fixed by exchange-coupling with the antiferromagnetic layer 32; an electrically conductive layer (intermediate layer) 37; a free layer (referred to as "F" in the drawing) 38 whose direction of magnetization varies according to external magnetization; an electrically conductive layer 39; and a cap layer (referred to as "CAP" in the drawing) 40 which are stacked on a substrate 11 in succession.

[0026]

The thin-film magnetic head 10 employs a so-called CPP (Current Perpendicular to Plane) structure in which a sense current Is flows in a layer thickness direction of the free layer 38. By way of a pair of electrode layers, the sense current Is is supplied to an MR film constituted by the free layer 38, electrically conductive layer 37, and the like. Provided as the electrode layers are a lower electrode layer (referred to as "BL" in the drawing) 42 and an upper electrode layer (referred to as "TL" in the drawing) 44. The upper electrode layer 44 is formed so as to cover the cap layer 40, whereas the lower electrode layer 42 is directly connected to the pinned layer 36.

[0027]

A region surrounding the antiferromagnetic layer 32 between the substrate 11 and the lower electrode layer 42 is formed with an insulating layer 46; whereas a region surrounding the free layer 38 between the lower electrode layer 42 and the upper electrode layer 44 is formed with an insulating layer 48. The insulating layers 46, 48 can be formed from Al_2O_3 or the like and prevents the sense current Is from leaking.

[0028]

The respective configurations of individual layers will now be explained in detail. The substrate 11 is formed from AlTiC (Al_2O_3-TiC) or the like, whereas the buffer layer 31 is formed thereon with a thickness of about 1 nm to about 10 nm. The buffer layer 31 can be formed from a conductive material such as Ta, NiFe, NiCr, NiFeCr, or the like, for example.

[0029]

The antiferromagnetic layer 32 is a layer for fixing the direction of magnetization of the pinned layer 36. The

antiferromagnetic layer 32 has a thickness of about 5 nm to about 20 nm, and can be formed from PtMn or the like. Employable as materials for forming the antiferromagnetic layer are either those of a type exhibiting antiferromagnetism even without heat treatment and inducing an exchange-coupling magnetic field with respect to a ferromagnetic material, or those of a type exhibiting antiferromagnetism upon heat treatment.

[0030]

The pinned layer 36 comprises a first ferromagnetic layer (referred to as "P_1" in the drawing) 33 in contact with the antiferromagnetic layer 32, a second ferromagnetic layer (referred to as "P_2" in the drawing) 35 whose direction of magnetization is opposite from that of the first ferromagnetic layer 33, and a nonmagnetic spacer layer 34 disposed between the layers 33, 35, thereby attaining a so-called synthetic structure.

[0031]

The first ferromagnetic layer 33 and second ferromagnetic layer 35 can be formed from CoFe or the like, for example, whereas the total thickness of the layers 33, 35 may be about 4 nm to about 15 nm.

[0032]

The nonmagnetic spacer layer 34 is formed from a nonmagnetic material such as Ru, Rh, Re, Cr, Zr, or the like, for example, whereas its thickness is about 0.2 nm to about 1.2 nm, for example. The nonmagnetic spacer layer 34 generates ferromagnetic exchange coupling between the first ferromagnetic layer 33 and the second ferromagnetic layer 35, thereby making the respective directions of magnetization of the layers 33, 35 opposite from each other. As shown in Fig. 1, the magnetization

of the first ferromagnetic layer 33 is directed to the air bearing surface (in the Y direction), whereas the magnetization of the second ferromagnetic layer 35 is fixed to the Y direction. The respective directions of magnetization in the first ferromagnetic layer 33 and second ferromagnetic layer 35 may be opposite from those in the state of Fig. 1 as well.

[0033]

The face of the second ferromagnetic layer 35 opposing the first ferromagnetic layer 33 has an area smaller than that of the face of the first ferromagnetic layer 33 opposing the second ferromagnetic layer 35. In other words, the first ferromagnetic layer 33 is wider than the second ferromagnetic layer 35 when seen from the upper side in the drawing. The nonmagnetic spacer layer 34 has substantially the same area as that of the second ferromagnetic layer 35 when seen from the upper side in the drawing.

[0034]

The lower electrode layer 42 is deposited on the region of first ferromagnetic layer 33 not covered with the nonmagnetic spacer layer 34 and second ferromagnetic layer 35, and on the insulating layer 46. Namely, the lower electrode layer 42 is in contact with the track-widthwise side faces of the second ferromagnetic layer 35 (in the X direction in the drawing) but not in contact with the track-widthwise side faces of the first ferromagnetic layer 33. The height of the lower electrode layer 42 in Fig. 1 is lower than the upper face of the second ferromagnetic layer 35 so as not to be in contact with the electrically conductive layer 37. This can prevent the electrically conductive layer 37 and the lower electrode layer 42 from short-

circuiting therebetween. The lower electrode layer 42 can be formed from an electrically conductive material such as Cu, NiFe and so on. The upper electrode layer 44 can be formed from a material similar to the lower electrode layer 42.

[0035]

The electrically conductive layer 37 is disposed between the pinned layer 36 and the free layer 38, and is formed from an electrically conductive material such as Cu. The electrically conductive layer 37 has a thickness of several nanometers, for example.

[0036]

The free layer 38 is one whose direction of magnetization changes under the influence of leakage magnetic fields of recording media such as hard disks. It has a thickness of about 1 nm to about 10 nm, and can be formed from a ferromagnetic material such as Fe, Co, Ni, FeCo, FeCoNi, CoZrNb, or the like, for example. Also, from the magnetic flux from a bias-applying layer (not depicted) comprising CoTa, CoCrPt, CoPt, or the like, the free layer 38 is caused to have a single domain in the −X direction in the drawing (which may be the X direction as well). As the air bearing surface comes closer to a magnetization transition area of a hard disk, the direction of magnetization of the free layer 38 swings so as to approach the positive or negative direction of Y axis. As the direction of magnetization of the free layer 38 swings, the current flowing through the electrically conductive layer 37 increases if the direction of magnetization of the second ferromagnetic layer 35 oriented in the Y-axis direction and the direction of magnetization of the free layer 38 coincide with each other, but decreases if the respective directions of

magnetization are opposite from each other.

[0037]

The electrically conductive layer 39 is formed from an electrically conductive material such as Cu, for example. It is not always necessary to provide the electrically conductive layer 39. The cap layer 40 is formed from an electrically conductive material such as Ta, for example.

[0038]

The thin-film magnetic head 10 in accordance with this embodiment is configured as in the foregoing. Thus configured thin-film magnetic head 10 yields the following effects. Since the lower electrode layer 42 is directly connected to the pinned layer 36, the sense current Is flows through the free layer 38, the electrically conductive layer 37, and the pinned layer (which is the second ferromagnetic layer 35 here), but basically does not flow through the antiferromagnetic layer 32. As a consequence, the antiferromagnetic layer 32 does not become so-called parasite resistance to the sense current, whereby a high magnetoresistance change ratio can be obtained. Further, the antiferromagnetic layer 32 can increase its thickness, since it does not become parasite resistance. As a result, the magnetization of the pinned layer 36 becomes stable, whereby the pin inversion can be suppressed.

[0039]

The lower electrode layer 42 is in contact with the track-widthwise side faces of the second ferromagnetic layer 35, but not in contact with the track-widthwise side faces of the first ferromagnetic layer 33. As a consequence, the sense current Is basically flows through the second ferromagnetic layer 35 but not

through the first ferromagnetic layer 33. The inventors have found that making the sense current Is flow as such can raise the maximum magnetoresistance change (difference between the magnetoresistance value at the time when the respective magnetizations of the free layer and pinned layer are in parallel and the magnetoresistance value at the time when they are not in parallel), thereby improving the magnetoresistance change ratio.

[0040]

As mentioned above, the face of the second ferromagnetic layer 35 opposing the first ferromagnetic layer 33 has an area smaller than that of the first ferromagnetic layer 33 opposing the second ferromagnetic layer 35. Therefore, when obtaining the second ferromagnetic layer 35 having a desirable pattern by utilizing a mask, the whole surface of the face of the second ferromagnetic layer 35 on the first ferromagnetic layer 33 side can oppose the first ferromagnetic layer 33 even when the mask forming position shifts to some extent. As a consequence, the magnetization of the second ferromagnetic layer 35 can firmly be fixed, whereby so-called pin inversion can effectively be suppressed.

[0041]

A method of making a thin-film magnetic head in accordance with the present invention will now be explained with reference to Figs. 2 to 9.

[0042]

First, as shown in Fig. 2, a buffer layer 31, an antiferromagnetic layer 32, and a first ferromagnetic layer 33 are stacked on a disk-shaped substrate 11 in this order, for example, by sputtering. This drawing shows a part of the disk-shaped

substrate 11.

[0043]

Subsequently, as shown in Fig. 3, a mask 51 is formed on the first ferromagnetic layer 33, whereas the buffer layer 31, the antiferromagnetic layer 32, and the first ferromagnetic layer 33 are patterned in conformity to the mask form, for example, by ion milling or the like. The mask 51 can be formed by the steps of coating the surface of the intermediate with a resist adapted to polymerize upon irradiation with light or an electron beam, irradiating the resist with light or an electron beam, and developing the resist. For facilitating liftoff, which will be explained later, it is preferred that a dent be formed under the mask 51 by a known technique. In practice, masks 51 are formed into a matrix on the substrate 11 by the number of thin-film magnetic heads to be obtained.

[0044]

Referring to Fig. 4, the next step will be explained. First, in the state where the mask 51 remains, an insulating layer 46 is deposited on the whole surface of the intermediate. Subsequently, the mask 51 is peeled off so as to carry out liftoff, thereby removing the mask and the materials deposited thereon. After removing the mask 51, the surface of the first ferromagnetic layer 33 may be etched at a relatively low speed in order to reduce the surface roughness of the first ferromagnetic layer 33, and then a material for forming the first ferromagnetic layer may be deposited thereon by a thickness on a par with the removed thickness. As a result of an experiment conducted by the inventors employing a technique in which, after etching the first ferromagnetic layer 33 for 20 minutes (which corresponds to a

thickness of 10 angstroms), the layer was deposited again thereon by a similar thickness, the pinning field of about 2.3 kOe was obtained.

[0045]

Next, as shown in Fig. 5, a nonmagnetic spacer layer 34, a second ferromagnetic layer (a layer to become the second ferromagnetic layer upon patterning thereafter in a strict sense) 35, an electrically conductive layer (intermediate layer) 37, a free layer 38, an electrically conductive layer 39, and a cap layer 40 are stacked in this order, for example, by sputtering.

[0046]

Subsequently, as shown in Fig. 6, a mask 52 is formed on the cap layer 40, and the cap layer 40 to the nonmagnetic spacer layer 34 are patterned in conformity to the mask form. The mask 52 can be formed by a technique similar to that of the former mask 51.

[0047]

Here, the projected area of the mask 52 onto the first ferromagnetic layer 33 is configured smaller than the area of the face (upper face in the drawing) 33a of the first ferromagnetic layer 33 opposing the mask 52. Namely, the first ferromagnetic layer 33 is made wider than the mask 52 when the intermediate is seen from the upper side in the drawing. While the mask 52 is formed after its positioning carried out by irradiating alignment marks on the substrate 11 with an electron beam, there is a fear of its forming position slightly deviating from the target position due to ultrafine processing. When the mask 52 has the size mentioned above, however, the whole surface of the face 35a of the second ferromagnetic layer 35 on the first ferromagnetic layer 33

side can oppose the first ferromagnetic layer 33 even if the position where the mask 52 is formed shifts to some extent. Therefore, the magnetization of the second ferromagnetic layer 35 can firmly be fixed, whereby so-called pin inversion can effectively be suppressed. As with the second ferromagnetic layer 35, the whole surface of the nonmagnetic spacer layer 34 opposes the first ferromagnetic layer 33.

[0048]

Referring to Fig. 7, the next step will be explained. First, in the state where the mask 52 remains, a lower electrode layer 42 is formed by sputtering, plating, IBD (Ion Beam Deposition), or the like. Here, the lower electrode layer 42 is formed so as to be in contact with the track-widthwise side faces of the second ferromagnetic layer 35 but not in contact with the track-widthwise side faces of the first ferromagnetic layer 33. When the lower electrode layer 42 is formed as such, the sense current basically flows through the second ferromagnetic layer 35, but not through the first ferromagnetic layer 33, whereby a high magnetoresistance change ratio can be realized. After forming the lower electrode layer 42, an insulating layer 48 is deposited on the whole surface of the intermediate by sputtering or the like. Thereafter, the mask 52 is pealed off, so as to carry out liftoff, thereby removing the mask and the materials deposited thereon.

[0049]

Subsequently, as shown in Fig. 8, an upper electrode layer 44 is deposited by sputtering, plating, IBD (Ion Beam Deposition), or the like. Fig. 9 shows a perspective view at the time when the upper electrode layer 44 is deposited (the electrode layers 42, 44 being indicated by broken lines). As shown in Fig. 9, the lower

electrode layer 42 extends in the track-widthwise direction (direction of arrow X), whereas the upper electrode layer 44 extends in the depth direction (direction of arrow Y) from the air bearing surface. By utilizing a known through hole forming technique or the like, the upper electrode layer 44 and lower electrode layer 42 are respectively connected to reproducing pads 19a, 19b shown in Fig. 11.

[0050]

A reproducing head section of a thin-film magnetic head is obtained in the foregoing manner. Though not explained in detail, an induction type recording head section is formed on the reproducing head section. The recording head section may be of longitudinal recording type in which a thin-film coil is held between upper and lower magnetic poles or of perpendicular recording type in which a thin-film coil is held between main and auxiliary magnetic poles.

[0051]

After the recording head section is formed so as to yield an intermediate of the thin-film magnetic head on the substrate 11, a plurality of bars are made by dicing. In each bar, a plurality of thin-film magnetic head intermediates are arranged in parallel. In the stage where such bars are made, lapping (grinding) for adjusting the MR height is carried out. After the lapping is finished, each bar is cut into blocks each having a thin-film magnetic head, so as to form a slider rail, thereby yielding a so-called head slider. This completes a series of steps of making the thin-film magnetic head 10.

[0052]

Though this embodiment relates to a case where the thin-

film magnetic head 10 is a so-called CPP-GMR head, it may be a TMR head as well. In the latter case, a tunnel barrier layer formed from a nonmagnetic insulating material is employed as the intermediate layer between the free layer and the pinned layer. The tunnel barrier layer is one through which electrons can pass while storing their spins by the tunnel effect. It has a thickness of about 0.5 nm to about 2 nm, and can be formed from an insulating material such as Al_2O_3, NiO, MgO, Ta_2O_5, TiO_2, or the like, for example.

[0053]

Each of the ferromagnetic layers 33, 35 of the pinned layer 36 and the free layer 38 may have a multilayer structure as well. The flowing direction of sense current I_S may also be opposite from that shown in Fig. 1, i.e., from the pinned layer 36 to the free layer 38.

[0054]

A head gimbal assembly and hard disk apparatus equipped with the thin-film magnetic head 10 will now be explained.

[0055]

Fig. 10 is a view showing a hard disk apparatus equipped with the thin-film magnetic head 10. The hard disk apparatus 1 is one in which a head gimbal assembly (HGA) 15 is actuated, so as to record/reproduce magnetic information into/from a recording surface of a hard disk 2, which rotates at a high speed, with the thin-film magnetic head 10. The head gimbal assembly 15 comprises a gimbal 12 mounted with the above-mentioned head slider 16 formed with the thin-film magnetic head 10, and a suspension arm 13 connected thereto, and is rotatable about a support shaft 14, for example, by a voice coil motor. As the head

gimbal assembly 15 is rotated, the head slider 16 moves in radial directions of the hard disk 2, i.e., in directions traversing track lines.

[0056]

Fig. 11 is an enlarged perspective view of the head slider 16. The head slider 16 has a substantially parallelepiped form, in which the thin-film magnetic head 10 is formed on a substrate 11. The front-side face in the drawing is an air bearing surface S opposing the recording surface of the hard disk 2. While the hard disk 2 rotates, the head slider 16 floats up due to the airflow accompanying the rotation, whereby the air bearing surface S separates from the recording surface of the hard disk 2. Recording pads 18a, 18b and reproducing pads 19a, 19b are connected to the thin-film magnetic head 10, whereas electric signal input/output lines (not depicted) to be connected to the individual pads are attached to the suspension arm 13 shown in Fig. 10. The recording pads 18a, 18b are electrically connected to the thin-film coil of the recording head section, whereas the reproducing pads 19a, 19b are electrically connected to the upper electrode layer 44 and lower electrode layer 42 of the reproducing head section, respectively.

[0057]

Since such head gimbal assembly 15 and hard disk apparatus 1 are equipped with the thin-film magnetic head 10, they can realize a high magnetoresistance change ratio, thereby being able to attain a high reproducing output in the hard disk apparatus.

[0058]

[Second Embodiment]

Next, referring to Fig. 12, a second embodiment of the present invention will be explained. In this embodiment, the lower electrode layer 42 is connected not to a side part of the second ferromagnetic layer 35 in the pinned layer 36, but to a side part of the first ferromagnetic layer 33. No sense current basically flows through the antiferromagnetic layer 32 in such a configuration as well, whereby the layer 32 can be prevented from becoming parasite resistance. This can improve the magnetoresistance change ratio of the thin-film magnetic head 10. However, since the first ferromagnetic layer 33 becomes resistance to the sense current in this embodiment, the first embodiment can realize a higher magnetoresistance change ratio.

[0059]

[Third Embodiment]

Now, referring to Fig. 13, a third embodiment of the present invention will be explained. In this embodiment, the pinned layer 36 has a single-layer structure (referred to as “P” in the drawing), whereas the lower electrode layer 42 is connected to a side part of the pinned layer 36. Though there is a fear of the magnetic field of the pinned layer 36 affecting the free layer 38 in such a configuration unlike the first embodiment having a synthetic structure, the antiferromagnetic layer 32 can be prevented from becoming parasite resistance, whereby a high magnetoresistance change ratio can be achieved.

[0060]

[Examples]

Effects of the present invention will now be explained more specifically with reference to Examples.

[0061]

As Example 1, a thin-film magnetic head corresponding to the first embodiment (see Fig. 1) was prepared. Namely, the upper electrode layer 44 was connected to the upper face of the cap layer 40, whereas the lower electrode layer 42 was connected to a side part of the second ferromagnetic layer 35 in the pinned layer 36. Table 1 shows the thickness and forming material of each layer.

TABLE. 1

	LAYER (NUMERALS CORRESPOND TO THOSE IN FIG. 1)	FORMING MATERIAL	THICKNESS (UNIT: ANGSTROM)
8	CAP LAYER 40	Ta, NiCr,・・・	10
7	ELECTRICALLY CONDUCTIVE LAYER 39	Cu	20
6	FREE LAYER 38	FeCo, NiFe,・・・	40
5	ELECTRICALLY CONDUCTIVE LAYER (INTERMEDIATE LAYER) 37	Cu	20
4	SECOND FERROMAGNETIC LAYER 35	FeCo AND THEIR ALLOYS	40
3	NONMAGNETIC SPACER LAYER 34	Ru, Rh	8
2	FIRST FERROMAGNETIC LAYER 33	FeCo AND THEIR ALLOYS	30
1	ANTIFERROMAGNETIC LAYER 32	PtMn	150

[0062]

Also, as Example 2, a thin-film magnetic head corresponding to the second embodiment (see Fig. 2) was prepared. The forming materials for the individual layers were the same as those in Example 1, whereas the lower electrode layer 42 was connected to a side part of the first ferromagnetic layer 33 in the pinned layer 36.

[0063]

Further prepared as Comparative Example was one in which the lower electrode layer was connected to the side of the antiferromagnetic layer 32 opposite from the side where the pinned layer was located as in conventional cases.

[0064]

The magnetoresistance change ratio was obtained for each of Examples 1 and 2 and Comparative Example according to the following expression (1):

MR (magnetoresistance change ratio) = $A \cdot \Delta R / R_{total}$ (1)

where $A \cdot \Delta R$ is the maximum magnetoresistance change (difference between the magnetoresistance value at the time when the respective magnetizations of the free layer and pinned layer are

in parallel and the magnetoresistance value at the time when they are not in parallel) multiplied by the cross-sectional area of the layer and is expressed in terms of mΩ·mm²; whereas R_{total} is the total resistance value of the layer through which the sense current flows.

[0065]

Thus obtained result was 1.36 mΩ·mm² in Comparative Example, whereas Examples 1 and 2 realized high magnetoresistance change ratios of 25.45 mΩ·mm² and 7.48 mΩ·mm², respectively. When simulations were carried out for Examples 1 and 2, their respective magnetoresistance change ratios to be obtained were 37.9 mΩ·mm² and 9.66 mΩ·mm², whereby the actually measured values were found to be close to the results of simulations.

[0066]

[Effect of the Invention]

As explained in the foregoing, the present invention can prevent the antiferromagnetic layer from becoming parasite resistance to the sense current, thus being able to realize a high magnetoresistance change ratio.

4 Brief Description of Drawings

[Fig. 1]

A schematic view showing a first embodiment of the thin-film magnetic head in accordance with the present invention.

[Fig. 2]

A view showing a manufacturing step of the thin-film magnetic head, illustrating a state where a first ferromagnetic layer and layers thereunder are stacked.

[Fig. 3]

A view showing a state where the first ferromagnetic layer and antiferromagnetic layer are patterned by utilizing a mask.

[Fig. 4]

A view showing a state after forming an insulating layer at side parts of the first ferromagnetic layer and antiferromagnetic layer and carrying out liftoff.

[Fig. 5]

A view showing a state where a nonmagnetic spacer layer to a cap layer are stacked.

[Fig. 6]

A view showing a state where the cap layer to the nonmagnetic spacer layer are patterned by utilizing a mask.

[Fig. 7]

A view showing a state where a side part of a second ferromagnetic layer is formed with a lower electrode layer, and an insulating layer is further formed thereon.

[Fig. 8]

A view showing a state where an upper electrode layer is formed on the cap layer.

[Fig. 9]

A perspective view schematically showing a thin-film magnetic head in a stage where the upper electrode layer is formed.

[Fig. 10]

A perspective view showing an embodiment of the hard disk apparatus in accordance with the present invention.

[Fig. 11]

An enlarged perspective view showing a head slider mounted with the hard disk apparatus of Fig. 10.

[Fig. 12]

A schematic view showing a second embodiment of the thin-film magnetic head in accordance with the present invention.

[Fig. 13]

A schematic view showing a third embodiment of the thin-film magnetic head in accordance with the present invention.

[Explanations of Numerals or Letters]

1...hard disk apparatus; 2...hard disk; 10...thin-film magnetic head; 11...substrate; 12...gimbal; 13...suspension arm; 15...head gimbal assembly; 16...head slider; 18a, 18b...recording pad; 19a, 19b...reproducing pad; 31...buffer layer; 32...antiferromagnetic layer; 33...first ferromagnetic layer; 34...nonmagnetic spacer layer; 35...second ferromagnetic layer; 36...pinned layer; 37...electrically conductive layer (intermediate layer); 38...free layer; 39...electrically conductive layer; 40...cap layer; 42...lower electrode layer; 44...upper electrode layer; 46, 48...insulating layer; 51, 52...mask; Is...sense current.

【書類名】　外国語図面

FIG.1

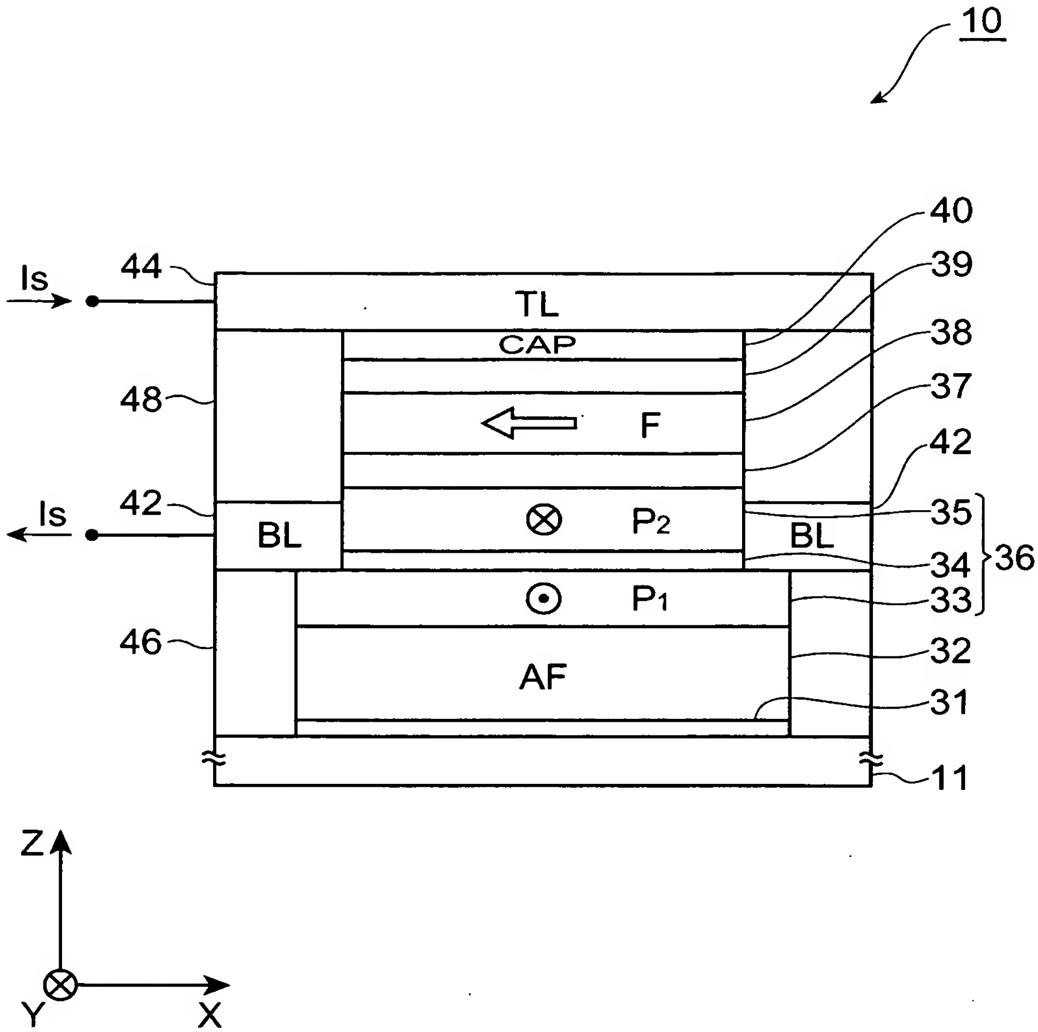


FIG.2

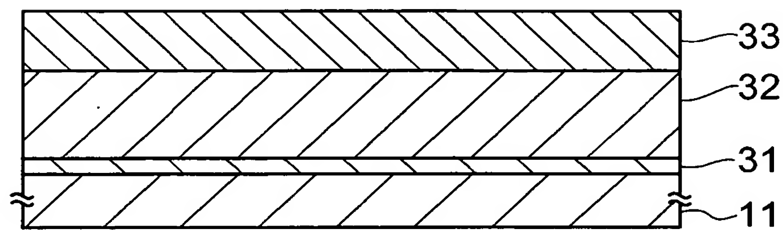


FIG.3

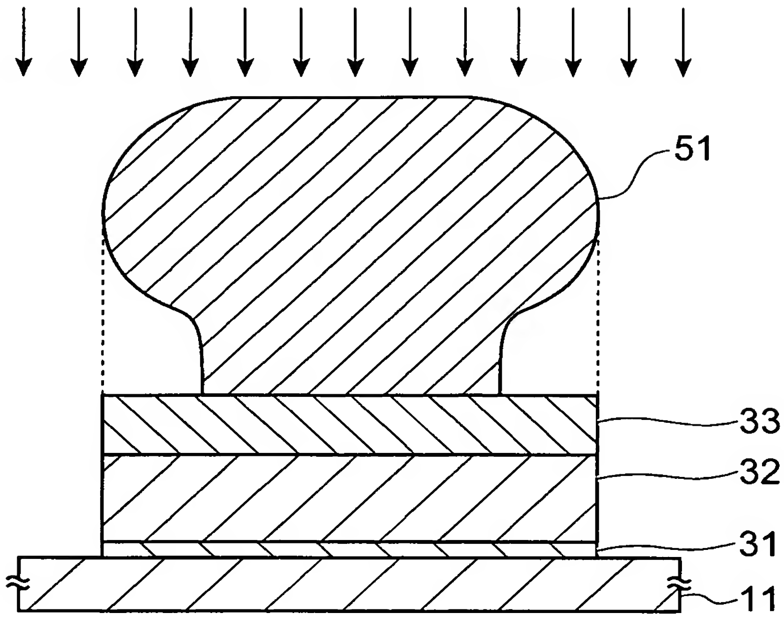


FIG.4

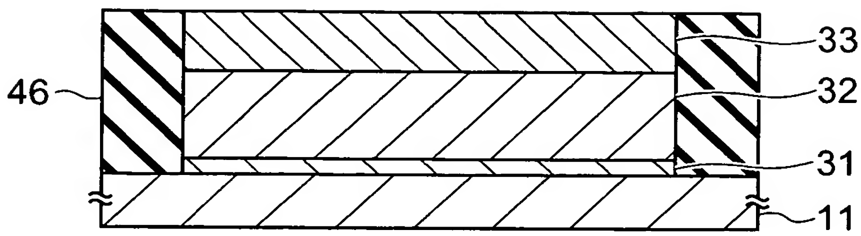


FIG.5

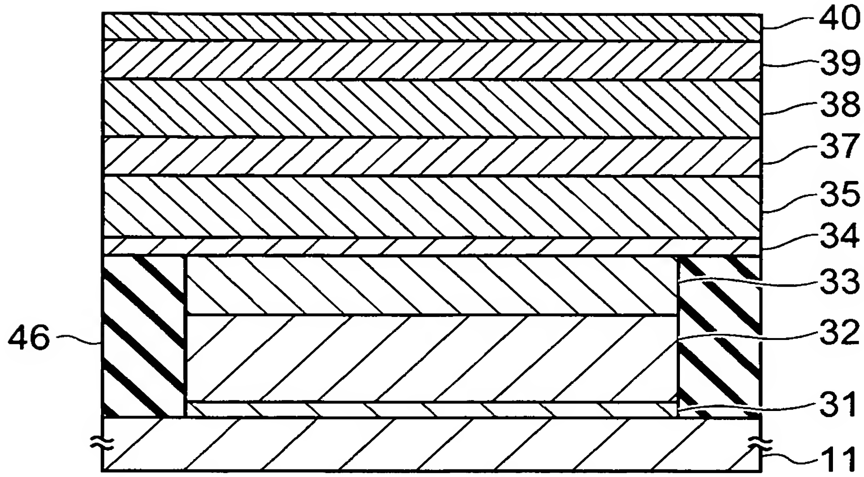


FIG.6

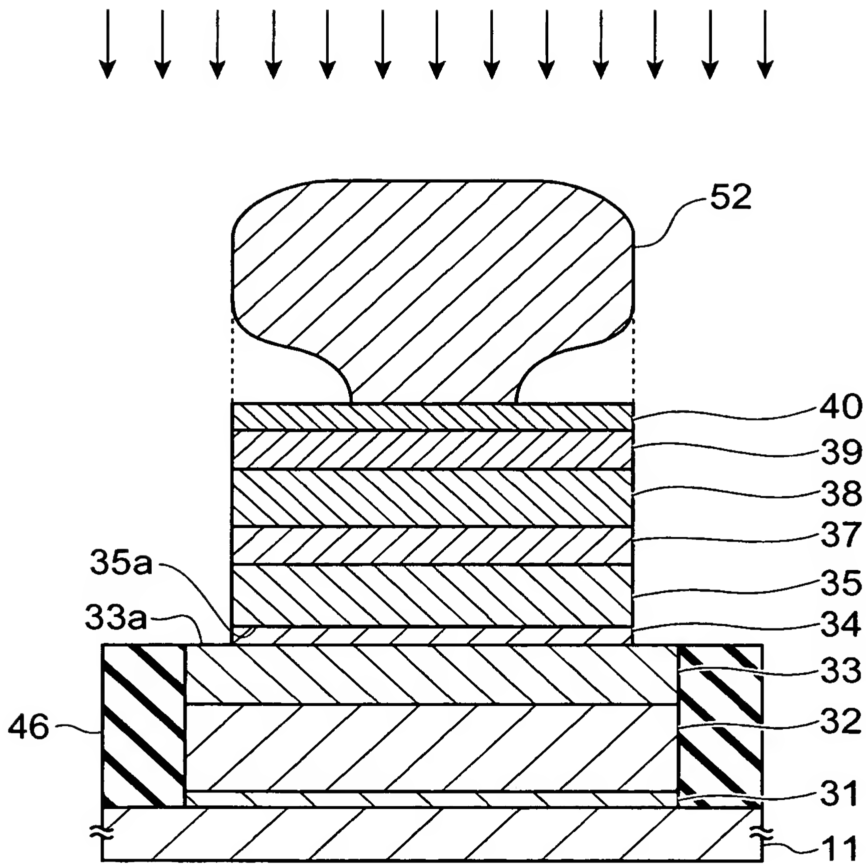


FIG.7

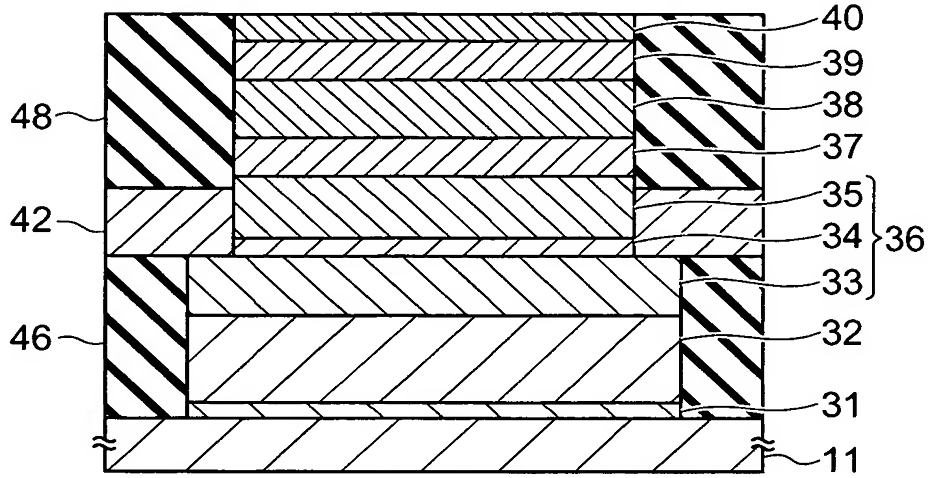
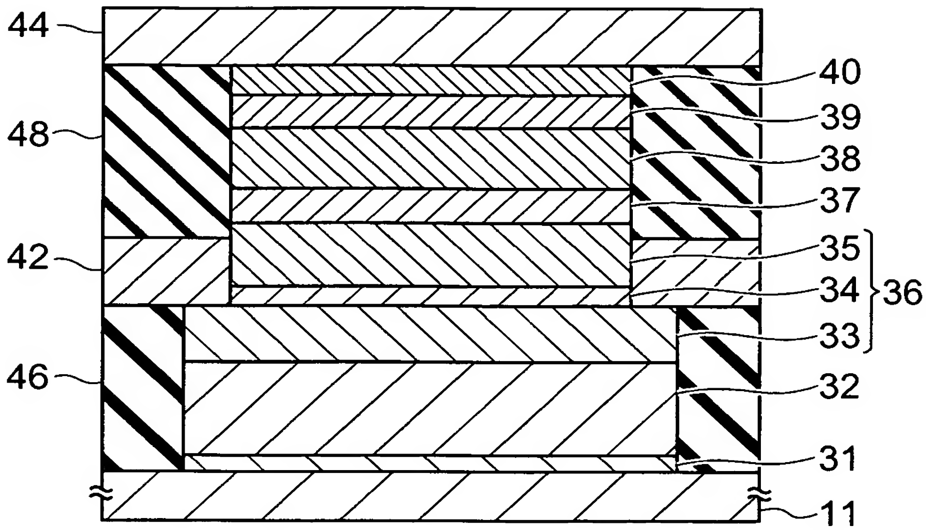


FIG.8



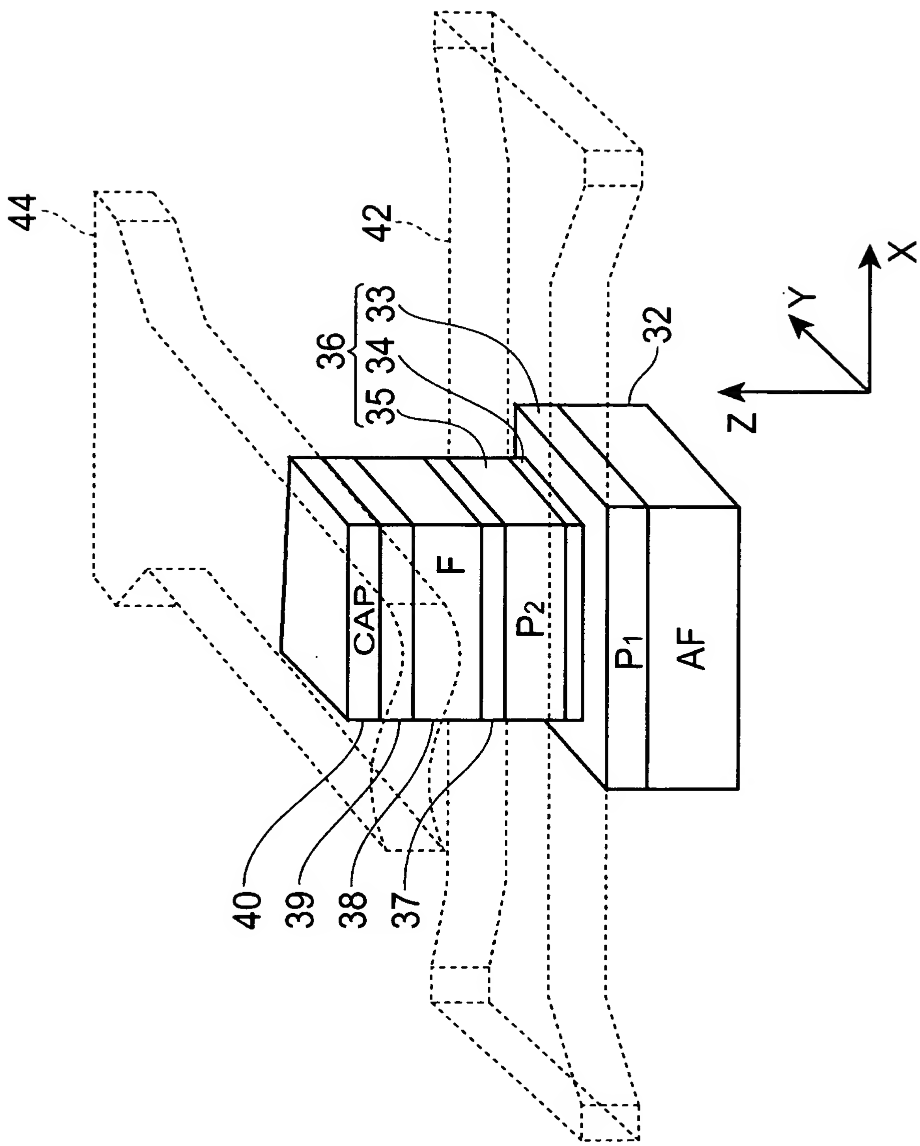


FIG.9

FIG.10

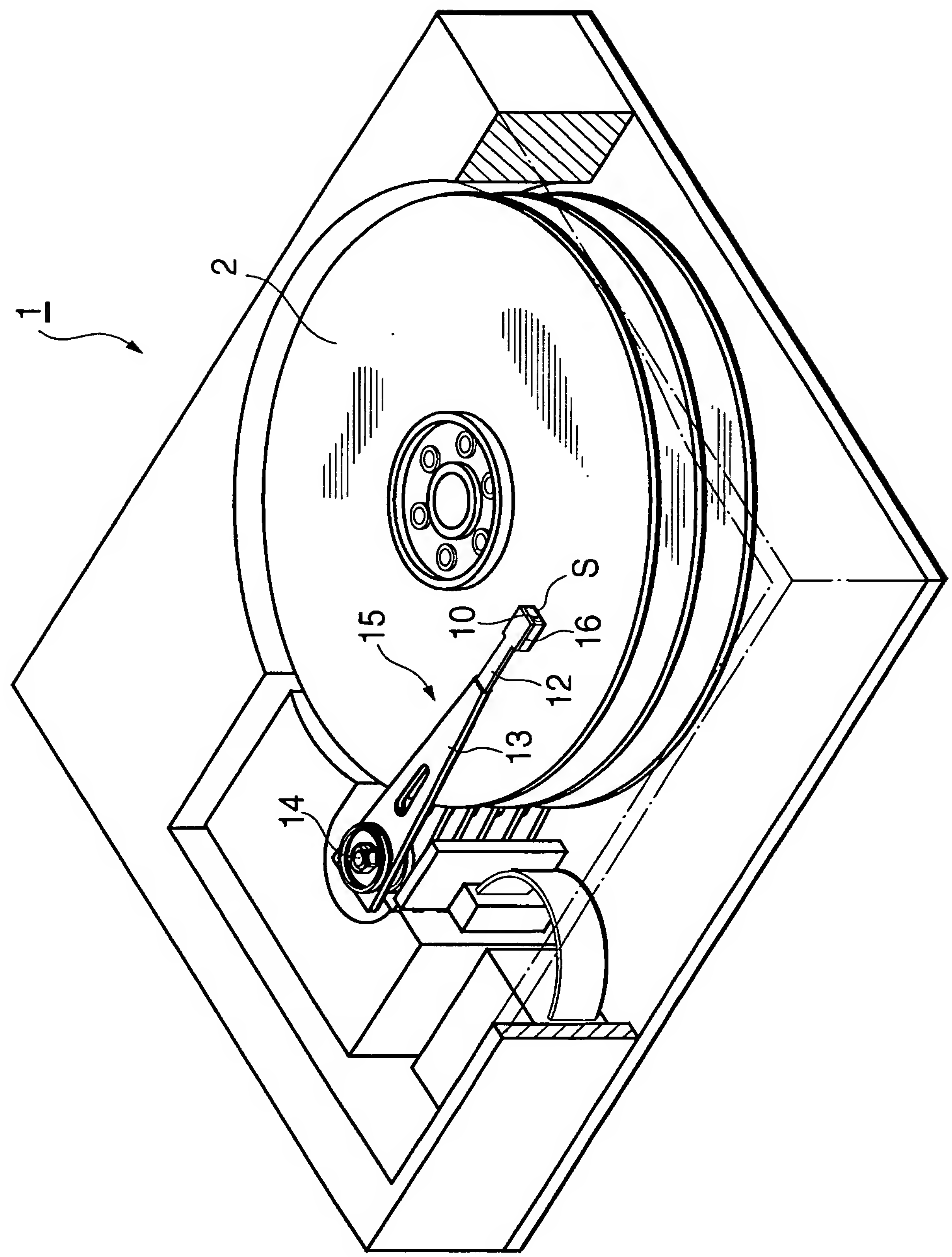


FIG.11

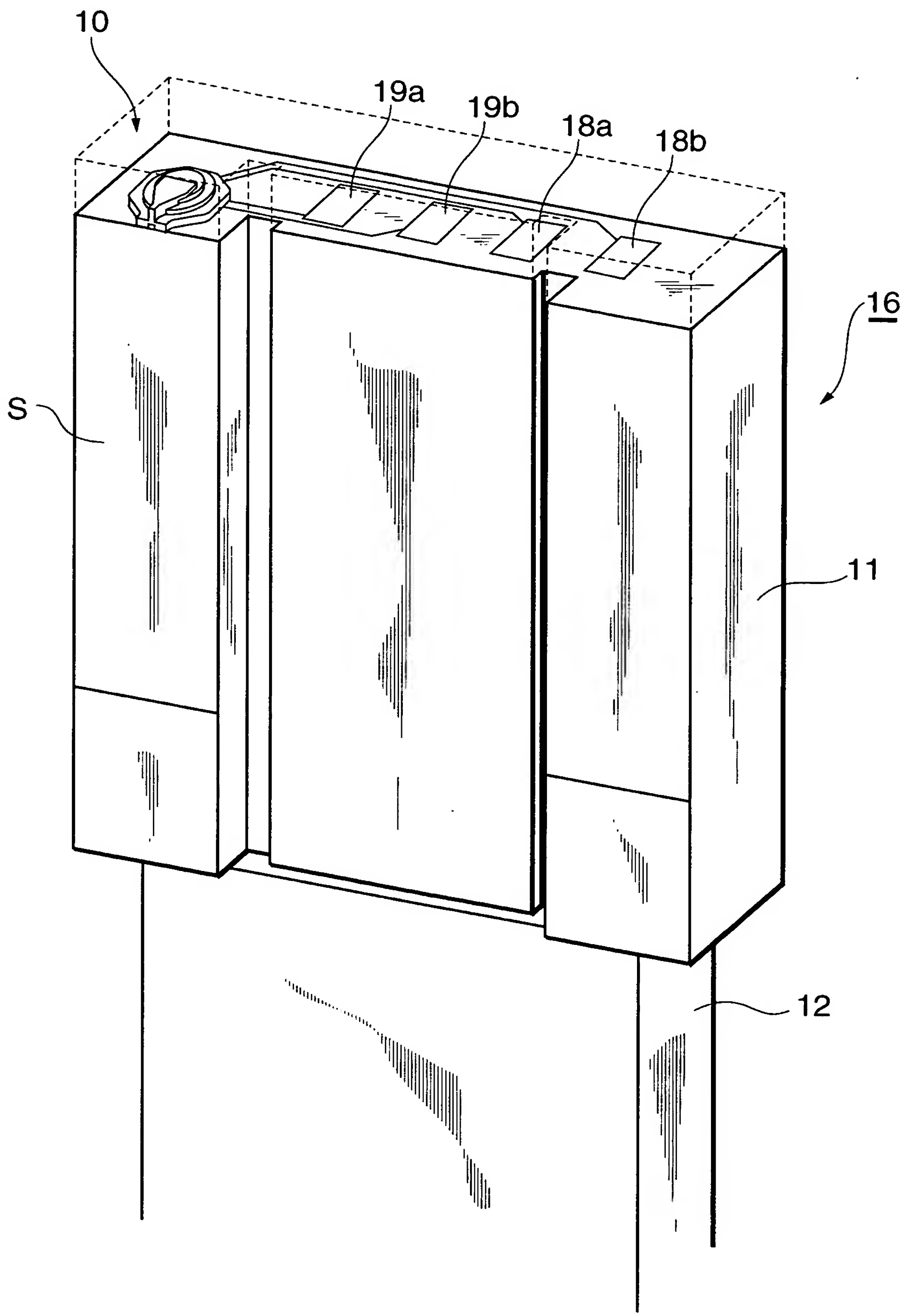
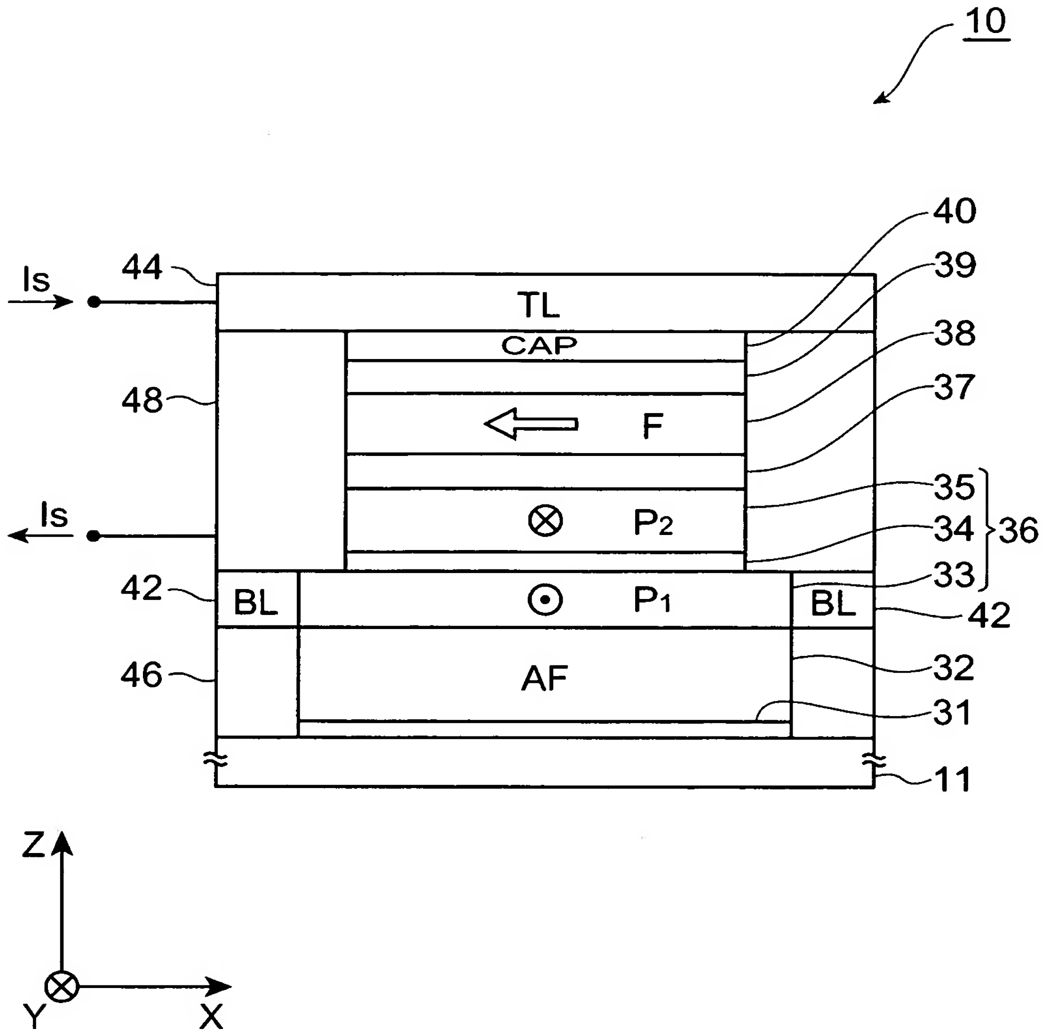


FIG.12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Is
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P1
BL
AF
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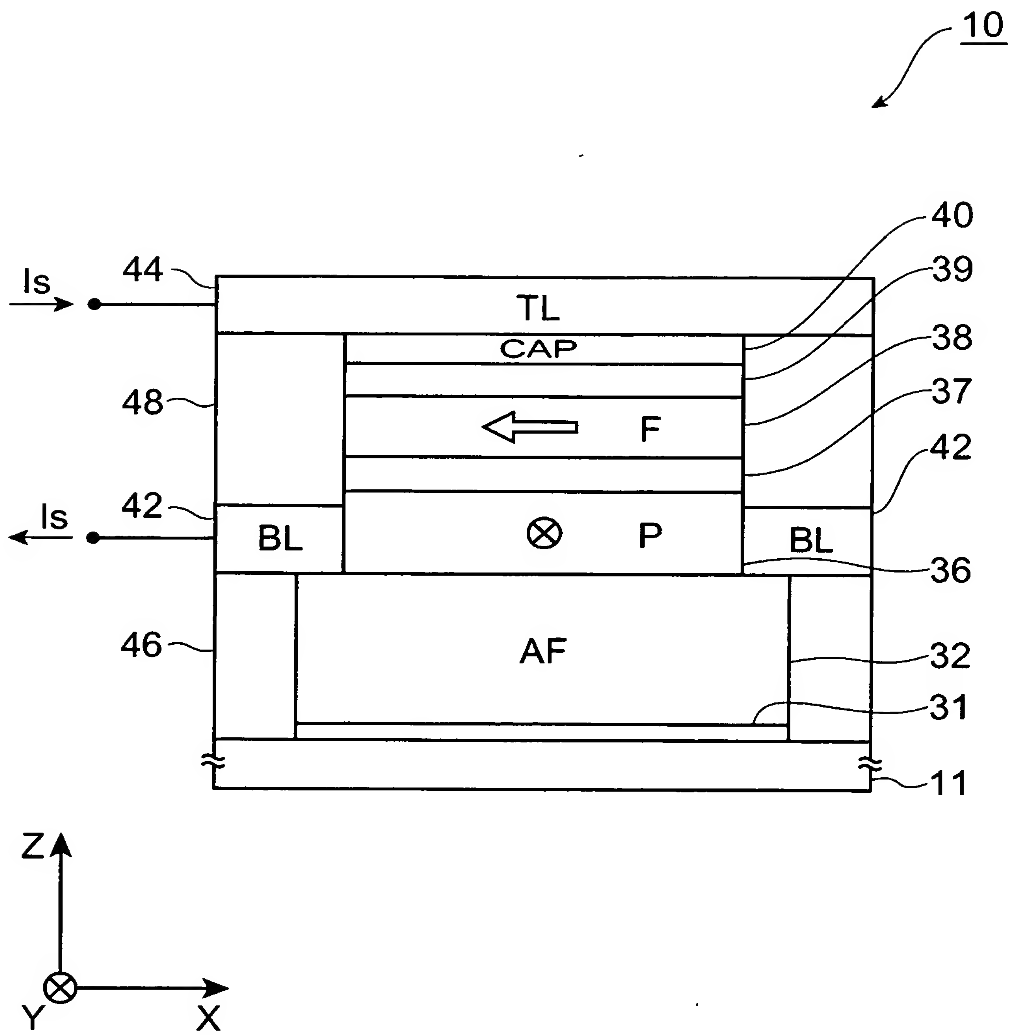
FIG.13



【書類名】　外国語要約書

1 Abstract

[Problem]　To provide a thin-film magnetic head, a head gimbal assembly, a hard disk apparatus, and a thin-film magnetic head which can realize a high magnetoresistance change ratio.

[Solving Means]　The thin-film magnetic head 10 of the present invention comprises an antiferromagnetic layer 32, a pinned layer 36 whose direction of magnetization is fixed by exchange-coupling with the antiferromagnetic layer, a free layer 38 whose direction of magnetization varies according to external magnetization, an intermediate layer 37 disposed between the pinned layer and free layer, and a pair of electrode layers 42, 44 for supplying a sense current in a layer thickness direction of the free layer. One electrode layer 42 is connected to the pinned layer 36. Due to this configuration, a sense current Is flows through the free layer 38, the intermediate layer 37, and the pinned layer 36, but basically does not flow through the antiferromagnetic layer 32. As a consequence, the antiferromagnetic layer 32 does not become resistance to the sense current, whereby a high magnetoresistance change ratio can be obtained.

2 Representative Drawing　　Fig. 1

出　願　人　履　歴　情　報

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